

STUDIES ON BENT COILS

by

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CERTIFICATE

This is to certify that the thesis entitled, '*Studies on Bent coils*' being submitted by **Ms. Monisha Mridha** to the Indian Institute of Technology, Delhi for award of Doctor of Philosophy is a record of bonafide research work carried out by her under my guidance and supervision in conformity with the rules and regulations of Indian Institute of Technology, Delhi.

The research report and results presented in this thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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Dedicated to

... My Beloved Parents

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Abstract

There has been a growing need in the industries for process intensification in order to achieve more efficient process, finer product and better economy. Improper mixing and heat-transfer results to lowered product quality, hence one requires more elaborate downstream process system and increased heat-transfer area. One of the foremost approaches is to use intensive reactor technologies with high mixing and heat transfer rates in place of conventional reactors. Coiled tube is an effective means of augmenting mixing and hence they are commonly used in industries for heating and cooling of process fluids due to their higher heat, mass transfer rate and more transfer area per unit volume of space as compared to straight tube. Coiled tubes such as helical and spiral coils find a wide variety of application as inline mixers, heat exchangers, chemical reactors, heat recovery processes, air conditioning and refrigeration systems, food and dairy processes, oil pipeline systems, steam generators, thermosyphons, nuclear reactors and other process equipments.

Mixing can be further enhanced by producing some chaos in the fluid. Chaotic advection is a novel passive technique for augmenting mixing of fluid. Coiled Flow Inverter (CFI) is one such innovative device. The principle of CFI is based on the phenomenon of flow inversions which are produced by changing the direction of centrifugal force in helically coiled tubes. If the direction of centrifugal force is rotated by any angle, the plane of vortex formation also rotates with the same angle. In the present work, attempts have been made to investigate the hydrodynamics and heat-transfer characteristics of compressed air at high flow rates in CFI heat exchanger at pilot plant scale. The tube side of CFI heat exchanger comprised of helical coils and 90° bends which are inserted in a closed shell. The heat exchanger is fitted with three types of baffles (central rod, square members and wedge shaped cut plates) to provide

higher turbulence and avoid channeling in the shell side. Experiments have been carried out with hot compressed air in the tube side of the heat exchanger. Cooling water or ambient air was used in the shell side in order to cool the hot compressed air in counter-current mode operation. Pressure drop and overall heat-transfer coefficient were calculated at various tube and shell side process conditions. The outer and inner heat-transfer coefficients were determined using Wilson plot technique. The results show that even at high Reynolds number, heat-transfer in CFI heat exchanger was higher as compared to coiled tubes. New empirical correlations have been developed for friction factor and Nusselt number predictions in the CFI heat exchanger.

In another study, heat transfer and pressure drop were numerically investigated in CFI at varying Dean number, Prandtl number and number of bends for air flowing under turbulent flow conditions. The three-dimensional governing equations for momentum and energy under the turbulent flow conditions were solved with a control-volume finite difference method (CVFDM) with second-order accuracy. The flow and thermal development, heat transfer coefficient and flow resistance in the CFI have been investigated. The effect of Prandtl number on fully developed heat transfer coefficient has also been reported. It is observed that heat transfer increases with increase in Prandtl number.

Numerical study was also conducted to investigate mixing of two miscible fluids for different process conditions by using scalar transport technique. A comparison was made for mixing performance of CFI with that of regular straight helical coiled tube at low flow rates. The effect of Dean number, Schmidt number and number of bends on the mixing efficiency was investigated. A new correlation has been proposed for unmixedness coefficient of CFI as a

function of Dean number, Schmidt number and number of bends. The performance of CFI under laminar flow condition shows that it can be used as an efficient in-line mixer.

Experimental studies were also carried out to investigate the hydrodynamics and heat transfer characteristics of a tube in tube helical heat exchanger at the pilot plant scale. Experiments were carried out in counter current mode operation with hot compressed air in the inner tube side and water in the outer tube side. The outer tube had semicircular plates to support the inner tube and also provided turbulence in the annulus region. The heat transfer coefficients were calculated in the inner as well as outer tube using Wilson plots. The numerically obtained Nusselt number and friction factor values in the inner and outer tubes are compared with the existing data in literature.

The technology transfer of CFI heat exchanger has also been done for the fertilizers and refinery industry in INDIA. The design of the CFI heat exchanger was carried out for the following two process streams. It was found that there will be energy saving if the CFI heat exchanger is replaced with the existing heat exchanger in the industry.

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